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**CADMIUM HAZARDS TO FISH, WILDLIFE, AND INVERTEBRATES:
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RESEARCH CENTER, LAUREL, MD - (USED AS A REFERENCE IN
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CADMUM HAZARDS TO FISH, WILDLIFE, AND INVERTEBRATES:
A SYNOPTIC REVIEW

by

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Cd conc. in field collections of selected species of flora & fauna. Values are in mg Cd/kg fresh weight (FW), dry weight (DW), or ash weight (AW)

Table 1. (Continued)

Ecosystem, taxonomic group, organism, tissue, location, and other variables	Concentration (mg/kg or ppm)	Reference ^a
<u>European starling, <i>Sturnus vulgaris</i></u>		
Whole, various U.S. locations		
Bakersfield, CA	0.24 FW	Martin and Nickerson
Lansing, MI	0.12 FW	1973
Elkins, WV	0.12 FW	
Farmington, NM	0.12 FW	
Phoenix, AZ	0.11 FW	
Other U.S. areas	<0.05 FW	
<u>Cooper's hawk, <i>Accipiter cooperii</i></u>		
Egg	0.12 (0.015 -0.24 FW	Snyder et al. 1973
<u>Mammals</u>		
<u>Short-tailed shrew, <i>Blarina brevicauda</i></u>		
Liver	1.3 FW	Jenkins 1980
Whole	0.4 FW	
<u>Cow, <i>Bos bovis</i></u>		
Distance from smelter		
Liver		
0.8 km	0.9 FW	
72.4 km	0.3 FW	
Kidney		
0.8 km	3.7 FW	
72.4 km	1.4 FW	
<u>Coyote, <i>Canis latrans</i></u>		
Kidney	0.4 FW	
<u>Elk, <i>Cervus</i> sp.</u>		
Liver	1.5 DW	
Kidney	8.1 DW	
Muscle	0.6 DW	
<u>Porcupine, <i>Erethizon dorsatum</i></u>		
Heart	0.4 FW	
<u>Meadow vole, <i>Microtus pennsylvanicus</i></u>		
Collected from fields near Oxford, Ohio, receiving sewage sludge for 4 years at yearly rate of 8960 kg sludge /ha.		

Table 1. (Concluded)

Ecosystem, taxonomic group, organism, tissue, location, and other variables	Concentration (mg/kg or ppm)	Reference ^a
Liver		
Adult males	0.8 FW	Maly and Barrett 1984
Adult females	3.1 FW	
Subadult males	1.2 FW	
Subadult females	1.1 FW	
Kidney		
Adult males	6.3 FW	
Adult females	19.1 FW	
Subadult males	3.5 FW	
Subadult females	6.2 FW	
From control fields		
Liver		
Adult males	0.7 FW	
Adult females	0.1 FW	
Subadult males	0.1 FW	
Subadult females	0.1 FW	
Kidney		
Adult males	0.3 FW	
Adult females	1.1 FW	
Subadult males	0.3 FW	
Subadult females	0.3 FW	
White-tailed deer, <u>Odocoileus virginianis</u>		
Kidney	0.7 - 11.7 FW	Jenkins 1980
Muscle	0.0 - 0.3 FW	
Liver	0.0 - 0.7 FW	
Gray squirrel, <u>Sciurus carolinensis</u>		
Kidney		
2 years old		
Urban area	15.9 FW	
Rural	2.0 - 4.6 FW	
Red squirrel, <u>Sciurus hudsonicus</u>		
Kidney	7.8 - 17.4 FW	
Liver	0.7 - 2.0 FW	
Eastern cottontail, <u>Sylvilagus floridanus</u>		
Liver	up to 2.1 FW	
Kidney	up to 13.5 FW	
Muscle	up to 0.5 FW	

^a Each reference applies to the values in the same row and in the rows that follow for which no other reference is indicated.

LITERATURE CITED

- Anas, R.E. 1974. Heavy metals in northern fur seals, Callorhinus ursinus, and harbor seals, Phoca vitulina richardii. U.S. Dep. Comm. Fish. Bull. 72:133-137.
- Anderlini, V. 1974. The distribution of heavy metals in the red abalone, Haliotis rufescens, on the California coast. Arch. Environ. Contam. Toxicol. 2:253-265.
- Anderson, R.L., C.T. Walbridge, and J.T. Fiandt. 1980. Survival and growth of Tanytarsus dissimilis (Chironomidae) exposed to copper, cadmium, zinc and lead. Arch. Environ. Contam. Toxicol. 9:329-335.
- Anderson, S.H., and R.I. Van Hook, Jr. 1973. Uptake and biological turnover of Cd in chipping sparrows, Spizella passerina. Environ. Physiol. Biochem. 3:243-247.
- Bebington, G.N., N.J. Mackay, R. Chvojka, R.J. Williams, A. Dunn, and E.H. Auty. 1977. Heavy metals, selenium and arsenic in nine species of Australian commercial fish. Aust. J. Mar. Freshwater Res. 28:277-286.
- Berland, B.R., D.J. Bonin, O.J. Guerin-Ancey, V.I. Kapkov, and D.P. Arlhac. 1977. Action de metaux lourds a des doses subletales sur les caracteristiques de la croissance chez la diatomee Skeletonema costatum. Mar. Biol. 42:17-30.
- Bertram, P.E., and B.A. Hart. 1979. Longevity and reproduction of Daphnia pulex (de Geer) exposed to cadmium-contaminated food or water. Environ. Pollut. 19:295-305.
- Beyer, W.N., O.H. Pattee, L. Sileo, D.J. Hoffman, and B.M. Mulhern. 1985. Metal contamination in wildlife living near two zinc smelters. Environ. Pollut. 38 A:63-86.
- Biesinger, K.E., and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. J. Fish. Res. Board Canada 29:1691-1700.
- Bohn, A., and B.W. Fallis. 1978. Metal concentrations (As, Cd, Cu, Pb and Zn) in shorthorn sculpins, Myoxocephalus scorpius (Linnaeus), and Arctic

- char, Salvelinus alpinus (Linnaeus), from the vicinity of Strathcona Sound, Northwest Territories. Water Res. 12:659-663.
- Brown, D.A., C.A. Bawden, K.W. Chatel, and T.R. Parsons. 1977. The wildlife community of Iona Island jetty, Vancouver, B.C., and heavy-metal pollution effects. Environ. Conserv. 4:213-216.
- Brungs, W.A., R.A. Carlson, W.B. Horning II, J.H. McCormick, R.L. Spehar, and J.D. Young. 1978. Effects of pollution on freshwater fish. J. Water Pollut. Control Fed. 50:1582-1637.
- Bryan, G.W. 1973. The occurrence and seasonal variation of trace metals in the scallops Pecten maximus (L.) and Chlamys opercularis (L.). J. Mar. Biol. Assoc. U.K. 53:145-166.
- Bryan, G.W., and L.G. Hummerstone. 1973. Adaptation of the polychaete Nereis diversicolor to estuarine sediments containing high concentrations of zinc and cadmium. J. Mar. Biol. Assoc. U.K. 53:839-857.
- Bryan, G.W., and L.G. Hummerstone. 1977. Indicators of heavy metal contamination in the Looe Estuary (Cornwall) with particular regard to silver and lead. J. Mar. Biol. Assoc. U.K. 57:75-92.
- Bryan, G.W., and L.G. Hummerstone. 1978. Heavy metals in the burrowing bivalve Scrobicularia plana from contaminated and uncontaminated estuaries. J. Mar. Biol. Assoc. U.K. 58:401-419.
- Bryan, G.W., and H. Uysal. 1978. Heavy metals in the burrowing bivalve Scrobicularia plana from the Tamar estuary in relation to environmental levels. J. Mar. Biol. Assoc. U.K. 58:89-108.
- Buhler, D.R., R.R. Claeys, and B.R. Mate. 1975. Heavy metal and chlorinated hydrocarbon residues in California sea lions (Zalophus californianus californianus). J. Fish. Res. Board Canada 32:2391-2397.
- Bull, K.R., R.K. Murton, D. Osborn, P. Ward, and L. Cheng. 1977. High levels of cadmium in Atlantic seabirds and sea-skaters. Nature 269:507-509.
- Butterworth, J., P. Lester, and G. Nickless. 1972. Distribution of heavy metals in the Severn Estuary. Mar. Pollut. Bull. 3:72-74.
- Cain, B.W., L. Sileo, J.C. Franson, and J. Moore. 1983. Effects of dietary cadmium on mallard ducklings. Environ. Res. 32:286-297.
- Calabrese, A., F.P. Thurberg, M.A. Dawson, and D.R. Wenzloff. 1975. Sublethal physiological stress induced by cadmium and mercury in winter flounder, Pseudopleuronectes americanus. Pages 15-21 in J.H. Koeman, and J.J.T.W.A. Strik (eds.). Sublethal effects of toxic chemicals on aquatic animals. Elsevier Sci. Publ. Co., Amsterdam.

- Canton, J.H., and W. Slooff. 1982. Toxicity and accumulation studies of cadmium (Cd^{2+}) with freshwater organisms of different trophic levels. *Ecotoxicol. Environ. Safety* 6:113-128.
- Carmichael, N.G., K.S. Squibb, and B.A. Fowler. 1979. Metals in the molluscan kidney: a comparison of two closely related bivalve species (*Argopecten*), using X-ray microanalysis and atomic absorption spectroscopy. *J. Fish. Res. Board Canada* 36:1149-1155.
- Carroll, J.J., S.J. Ellis, and W.S. Oliver. 1979. Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*). *Bull. Environ. Contam. Toxicol.* 22:575-581.
- Chapman, G.A. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. *Trans. Am. Fish. Soc.* 107:841-847.
- Chapman, G.A., and D.G. Stevens. 1978. Acutely lethal levels of cadmium, copper, and zinc to adult male coho salmon and steelhead. *Trans. Am. Fish. Soc.* 107:837-840.
- Christensen, G., E. Hunt, and J. Fiant. 1977. The effect of methylmercuric chloride, cadmium chloride and lead nitrate on six biochemical factors of the brook trout (*Salvelinus fontinalis*). *Toxicol. Appl. Pharmacol.* 42: 523-530.
- Conway, H.L. 1978. Sorption of arsenic and cadmium and their effects on growth, micronutrient utilization, and photosynthetic pigment composition of Asterionella formosa. *J. Fish. Res. Board Canada* 35:286-294.
- Cossa, D. 1976. Sorption du cadmium par une population de la diatomée Phaeodactylum tricornutum en culture. *Mar. Biol.* 34:163-167.
- Davies, P.H. 1976. Use of dialysis tubing in defining the toxic fractions of heavy metals in natural waters. Pages 110-117 in R.W. Andrew, P.V. Hodson, and D.E. Konasewich (eds.). *Toxicity to biota of metal forms in natural water*. Proc. Workshop, Duluth, MN, October 7-8, 1975, Great Lakes Res. Advis. Bd., Int. Joint Comm.
- Dawson, M.A., E. Gould, F.P. Thurberg, and A.J. Calabrese. 1977. Physiological response of juvenile striped bass, Morone saxatilis, to low levels of cadmium and mercury. *Chesapeake Sci.* 18:353-359.
- Drasch, G.A. 1983. An increase of cadmium body burden for this century: an investigation on human tissues. *Sci. Total Environ.* 26:111-120.
- Eaton, J.G. 1974. Chronic cadmium toxicity to the bluegill (Lepomis macrochirus Rafinesque). *Trans. Am. Fish. Soc.* 103:729-735.
- Eisler, R. 1971. Cadmium poisoning in Fundulus heteroclitus (Pisces:

Cyprinodontidae) and other marine organisms. J. Fish Res. Board Canada 28:1225-1234.

Eisler, R. 1974. Radiocadmium exchange with seawater by Fundulus heteroclitus (L.) (Pisces: Cyprinodontidae). J. Fish Biol. 6:601-612.

Eisler, R. 1981. Trace metal concentrations in marine organisms. Pergamon Press, New York. 687 pp.

Eisler, R. 1984. Trace metal changes associated with age of marine vertebrates. Biol. Trace Element Res. 6:165-180.

Eisler, R., G.E. Zaroogian, and R.J. Hennekey. 1972. Cadmium uptake by marine organisms. J. Fish. Res. Board Canada 29:1367-1369.

EPA. 1973. Water Quality Criteria 1972. U.S. Environ. Protection Agency Rep. R3-73-033. 594 pp.

EPA. 1980. Ambient water quality criteria for cadmium. U.S. Environ. Protection Agency Rep. 440/5-80-025. 183 pp.

Eustace, I.J. 1974. Zinc, cadmium, copper and manganese in species of finfish and shellfish caught in the Derwent Estuary, Tasmania. Aust. J. Mar. Freshwater Res. 25:209-220.

Ferard, J.F., J.M. Jouany, R. Truhaut, and P. Vasseur. 1983. Accumulation of cadmium in a freshwater food chain experimental model. Ecotoxicol. Environ. Safety 7:43-52.

Ferm, V.H., and W.M. Layton, Jr. 1981. Teratogenic and mutagenic effects of cadmium. Pages 743-756 in J.O. Nriagu (ed.). Cadmium in the environment. Part 2, Health effects. John Wiley, New York.

Finlayson, B.J., and K.M. Verreue. 1982. Toxicities of copper, zinc, and cadmium mixtures to juvenile chinook salmon. Trans. Am. Fish. Soc. 111:645-650.

Foster, P. 1976. Concentrations and concentration factors of heavy metals in brown algae. Environ. Pollut. 10:45-53.

Gardiner, J. 1974. The chemistry of cadmium in natural water-II. The adsorption of cadmium on river muds and naturally occurring solids. Water Res. 8:157-164.

Gentile, S.M., J.H. Gentile, J. Walker, and J.F. Heltshe. 1982. Chronic effects of cadmium on 2 species of mysid shrimp Mysidopsis bahia and Mysidopsis bigelowi. Hydrobiologia 93:195-204.

George, S.G., B.J.S. Pirie, and T.L. Coombs. 1980. Isolation and elemental analysis of metal-rich granules from the kidney of the scallop, Pecten

- maximus (L.). J. Exp. Mar. Biol. Ecol. 42:143-156.
- Giesy, J.P., Jr., H.J. Kania, J.W. Bowling, R.L. Knight, S. Mashburn, and S. Clarkin. 1979. Fate and biological effects of cadmium introduced into channel microcosms. U.S. Environ. Protection Agency Rep. 600/3-79-039. 157 pp.
- Giesy, J.P., Jr., G.J. Leversee, and D.R. Williams. 1977. Effects of naturally occurring aquatic organic fractions on cadmium toxicity to Simocephalus serrulatus (Daphnidae) and Gambusia affinis (Poeciliidae). Water Res. 11:1013-1020.
- Gish, C.D., and R.E. Christensen. 1973. Cadmium, nickel, lead and zinc in earthworms from roadside soil. Environ. Sci. Technol. 7:1060-1072.
- Goldberg, E.D., V.T. Bowen, J.W. Farrington, G. Harvey, J.H. Martin, P.L. Parker, R.W. Risebrough, W. Robertson, E. Schneider, and E. Gamble. 1978. The mussel watch. Environ. Conserv. 5:101-125.
- Greig, R.A., D.R. Wenzloff, A. Adams, B. Nelson, and C. Shelpuk. 1977. Trace metals in organisms from ocean disposal sites of the middle eastern United States. Arch. Environ. Contam. Toxicol. 6:395-409.
- Greig, R.A., D.R. Wenzloff, C.L. MacKenzie, Jr., A.S. Merrill, and V.S. Zdanowicz. 1978. Trace metals in sea scallops, Placopecten magellanicus, from eastern United States. Bull. Environ. Contam. Toxicol. 19:326-334.
- Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17:66-73.
- Hamanaka, T., H. Kato, and T. Tsujita. 1977. Cadmium and zinc in ribbon seal, Histriophoca fasciata, in the Okhotsk Sea. Pages 547-561 in Special Volume, Res. Inst. N. Pac. Fish. Hokkaido Univ.
- Hammons, A.S., J.E. Huff, H.M. Braunstein, J.S. Drury, C.R. Shriner, E.B. Lewis, B.L. Whitfield, and L.E. Towill. 1978. Reviews of the environmental effects of pollutants: IV Cadmium. U.S. Environ. Protection Agency Rep. 600/1-78-026. 251 pp.
- Hardisty, M.W., S. Kartar, and M. Sainsbury. 1974. Dietary habits and heavy metal concentrations in fish from the Severn Estuary and Bristol Channel. Mar. Pollut. Bull. 5:61-63.
- Harris, J.E., G.J. Fabris, P.J. Statham, and F. Tawfik. 1979. Biogeochemistry of selected heavy metals in Western Port, Victoria, and use of invertebrates as indicators with emphasis on Mytilus edulis planulatus. Aust. J. Mar. Freshwater Res. 30:159-178.
- Haug, A., S. Melson, and S. Omang. 1974. Estimation of heavy metal pollution in two Norwegian fjord areas by analysis of the brown alga Ascophyllum

nodosum. Environ. Pollut. 7:179-192.

Heinz, G.H., and S.D. Haseltine. 1983. Altered avoidance behavior of young black ducks fed cadmium. Environ. Toxicol. Chem. 2: 419-421.

Heit, M. 1979. Variability of the concentrations of seventeen trace elements in the muscle and liver of a single striped bass, Morone saxatilis. Bull. Environ. Contam. Toxicol. 23:1-5.

Horowitz, A., and B.J. Presley. 1977. Trace metal concentrations and partitioning in zooplankton, neuston, and benthos from the south Texas Outer Continental Shelf. Arch. Environ. Contam. Toxicol. 5:241-255.

Hughes, J.S. 1973. Acute toxicity of thirty chemicals to striped bass (Morone saxatilis). Proc. Western Assoc. State Game Fish Comm. 53:399-413.

Hulse, M., J.S. Mahoney, G.D. Schroder, C.S. Hacker, and S.M. Pier. 1980. Environmentally acquired lead, cadmium, and manganese in the cattle egret, Bubulcus ibis, and the laughing gull, Larus atricilla. Arch. Environ. Contam. Toxicol. 9:65-78.

Hutton, M. 1983a. A prospective atmospheric emission inventory for cadmium: the European community as a study area. Sci. Total Environ. 29:29-48.

Hutton, M. 1983b. Sources of cadmium in the environment. Ecotoxicol. Environ. Safety 7:9-24.

Jenkins, D.W. 1980. Biological monitoring of toxic trace metals. Volume 2. Toxic trace metals in plants and animals of the world. Part 1. U.S. Environ. Protection Agency Rep. 600/3-80-090. 503 pp.

Julshamn, K., and O.R. Braekkan. 1975. Determination of trace elements in fish tissues by the standard addition method. Atom. Absorp. News1. 14:49-52.

Julshamn, K., and O.R. Braekkan. 1978. The relation between the concentration of some main elements and the stages of maturation of ovaries in cod (Gadus morrhua). Fiskeridir. Skr. Ser. Ernaering 1:1-15.

Khalid, R.A., R.P. Gambrell, and W.H. Patrick, Jr. 1981. Chemical availability of cadmium in Mississippi River sediment. J. Environ. Qual. 10:523-528.

Kopfler, F.C., and J. Mayer. 1967. Studies of trace metals in shellfish. Pages 67-80 in Proc. Gulf South Atlantic States Shellfish Sanit. Res. Conf.

Korte, F. 1983. Ecotoxicology of cadmium: general review. Ecotoxicol. Environ. Safety 7:3-8.

- ida, H., S. Kimura, and M. Yokote. 1980. Accumulation and biological effects of cadmium in rainbow trout. Bull. Jpn. Soc. Sci. Fish. 46:97-103.
- ida, H., S. Kimura, and M. Yokote, and Y. Matida. 1973. Acute and chronic toxicity, uptake and retention of cadmium in freshwater organisms. Bull. Freshwater Fish. Res. Lab. (Tokyo) 22:157-165.
- le, E. 1977. Heavy metal pollution in Trondheimsfjorden, Norway, and the recorded effects on the fauna and flora. Environ. Pollut. 12:187-198.
- therland, T.M., and J.D. Burton. 1974. The occurrence of some trace metals in coastal organisms with particular reference to the Solent region. J. Mar. Biol. Assoc. U.K. 54:457-468.
- ett, R.J., W.H. Gutenmann, I.S. Pakkala, W.D. Youngs, D.J. Lisk, G.E. Burdick, and E.J. Harris. 1972. A survey of total cadmium content of 406 fish from 49 New York State freshwaters. J. Fish. Res. Board Canada 29:1283-1290.
- kay, N.J., M.N. Kazacos, R.J. Williams, and M.I. Leedor. 1975. Selenium and heavy metals in black marlin. Mar. Pollut. Bull. 6:57-60.
- ckard, C. 1983. Impact of cadmium in the environment of the Federal Republic of Germany. Ecotoxicol. Environ. Safety 7:111-116.
- ly, M.S., and G.W. Barrett. 1984. Effects of two types of nutrient enrichment on the structure and function of contrasting old-field communities. Am. Midl. Nat. 111:342-357.
- rshall, J.S. 1978. Population dynamics of Daphnia galeata mendotae as modified by chronic cadmium stress. J. Fish. Res. Board Canada 35:461-469.
- rtin, J.H., and A.R. Flegal. 1975. High copper concentrations in squid livers in association with elevated levels of silver, cadmium, and zinc. Mar. Biol. 30:51-55.
- rtin, W.E., and P.R. Nickerson. 1973. Mercury, lead, cadmium, and arsenic residues in starlings - 1971. Pestic. Monit. J. 7:67-72.
- ly, T.W., and G.L. McKinney. 1981. Cadmium, lead, mercury, arsenic, and selenium concentrations in freshwater fish, 1976-77 -- National Pesticide Monitoring Program. Pestic. Monit. J. 15:14-38.
- Intosh, A.W., B.K. Shephard, R.A. Mayes, G.J. Atchison, and D.W. Nelson. 1978. Some aspects of sediment distribution and macrophyte cycling of heavy metals in a contaminated lake. J. Environ. Qual. 7:301-305.

- Melhuus, A., K.L. Seip, H.M. Seip, and S. Myklestad. 1978. A preliminary study of the use of benthic algae as biological indicators of heavy metal pollution in Sorfjorden, Norway. Environ. Pollut. 15:101-107.
- Myklestad, S., I. Eide, and S. Melsom. 1978. Exchange of heavy metals in Ascophyllum nodosum (L.) Le Jod. in situ by means of transplanting experiments. Environ. Pollut. 16:277-284.
- Nomiyama, K. 1982. Carcinogenicity of cadmium. Jpn. J. Indust. Health 24:13-23.
- NRCC. 1979. Effects of cadmium in the Canadian environment. Nat. Res. Coun. Canada, NRCC No. 16743. 148 pp.
- Parslow, J.L.F., D.J. Jefferies, and M.C. French. 1972. Ingested pollutants in puffins and their eggs. Bird Study 19:18-33.
- Passco, D., and D.L. Matthey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback, Gasterosteus aculeatus L. J. Fish Biol. 11:207-215.
- Pesch, G.G., and N.E. Stewart. 1980. Cadmium toxicity to three species of invertebrates. Mar. Environ. Res. 3:145-156.
- Peterson, R.H., J.L. Metcalfe, and S. Ray. 1983. Effects of cadmium on yolk utilization, growth, and survival of Atlantic salmon alevins and newly feeding fry. Arch. Environ. Contam. Toxicol. 12:37-44.
- Hillips, J.H. 1976. The common mussel Mytilus edulis as an indicator of pollution by zinc, cadmium, lead and copper. II. Relationship of metals in the mussel to those discharged by industry. Mar. Biol. 38:71-80.
- Pickering, Q.H., and M. Gast. 1972. Acute and chronic toxicity of cadmium to the fathead minnow (Pimephales promelas). J. Fish. Res. Board Canada 29:1099-1106.
- Preston, A., D.F. Jeffries, J.W.R. Dutton, B.R. Harvey, and A.K. Steele. 1972. British Isles coastal waters: the concentrations of selected heavy metals in sea water, suspended matter and biological indicators - a pilot survey. Environ. Pollut. 3:69-82.
- Pringle, B.H., D.E. Hissong, E.L. Katz, and S.T. Mulawka. 1968. Trace metal accumulation by estuarine mollusks. J. Sanit. Engin. Div. 94 SA3:455-475.
- Tkowsky, D.A., S.J. Thrower, I.J. Eustace, and J. Olley. 1974. A numerical study of the concentration of some heavy metals in Tasmanian oysters. J. Fish. Res. Board Canada 31:1165-1171.
- Y, S., D. McLeese, and D. Pezzack. 1980. Accumulation of cadmium by Nereis virens. Arch. Environ. Contam. Toxicol. 9:1-8.

- Revis, N.W., A.R. Zinsmeister, and R. Bull. 1981. Athero sclerosis and hypertension induction by lead and cadmium ions: an effect prevented by calcium ion. Proc. Nat. Acad. Sci. 78:6494-6498.
- Reynolds, B.H. 1979. Trace metals monitoring at two ocean disposal sites. U.S. Environ. Protection Agency Rep. 600/3-79-037. 64 pp. (Avail. from Nat. Tech. Inf. Serv., U.S. Dep. Comm., Springfield, VA 22161)
- Richardson, M.E., M.R.S. Fox, and B.E. Fry, Jr. 1974. Pathological changes produced in Japanese quail by ingestion of cadmium. J. Nutr. 104:323-338.
- Riley, J.P., and D.A. Segar. 1970. The distribution of the major and some minor elements in marine animals. I. Echinoderms and coelenterates. J. Mar. Biol. Assoc. U.K. 50:721-730.
- Roberts, K.S., A. Cryer, J. Kay, J.F. de L.G. Solbe, J.R. Wharfe, and W.R. Simpson. 1979. The effects of exposure to sub-lethal concentrations of cadmium on enzyme activities and accumulation of the metal in tissues and organs of rainbow and brown trout (Salmo gairdneri, Richardson and Salmo trutta fario L.). Comp. Biochem. Physiol. 62C:135-140.
- Robertson, D.E., L.A. Rancitelli, J.C. Langford, and R.W. Perkins. 1972. Battelle-Northwest contribution to the IDOE base-line study. Battelle Pac. Northwest Lab., Richland, Wash.:1-46.
- Rombough, P.J., and E.T. Garside. 1982. Cadmium toxicity and accumulation in eggs and alevis of Atlantic salmon, Salmo salar. Can. J. Zool. 60:2006-2014.
- Rosenberg, R. 1977. Effects of dredging operations on estuarine benthic macrofauna. Mar. Pollut. Bull. 8:102-104.
- Sarkar, A.K., and R. Mondal. 1973. Injurious effect of cadmium on testis of domestic pigeon and its prevention by zinc. Indian J. Exp. Biol. 11:108-109.
- Segar, D.A., J.D. Collins, and J.P. Riley. 1971. The distribution of the major and some minor elements in marine animals. Part II. molluscs. J. Mar. Biol. Assoc. U.K. 51:131-136.
- Shephard, B.K., A.W. McIntosh, G.J. Atchison, and D.W. Nelson. 1980. Aspects of the aquatic chemistry of cadmium and zinc in a heavy metal contaminated lake. Water Res. 14:1061-1066.
- Shuster, C.N., Jr., and B.H. Pringle. 1969. Trace metal accumulation by the American oyster, Crassostrea virginica. 1968 Proc. Nat. Shellfish. Assoc. 59:91-103.

- Siewicki, T.C., J.E. Balthrop, and J.S. Sydlowski. 1983. Iron metabolism of mice fed low levels of physiologically bound cadmium in oyster or cadmium chloride. *J. Nutr.* 113:1140-1149.
- Sims, R.R., Jr., and B.J. Presley. 1976. Heavy metal concentrations in organisms from an actively dredged Texas bay. *Bull. Environ. Contam. Toxicol.* 16:520-527.
- Snyder, N.F.R., H.A. Snyder, J.L. Lincer, and R.T. Reynolds. 1973. Organochlorines, heavy metals, and the biology of North American accipiters. *BioScience* 23:300-305.
- Spehar, R.L., R.L. Anderson, and J.T. Fiandt. 1978. Toxicity and bioaccumulation of cadmium and lead in aquatic invertebrates. *Environ. Pollut.* 15:195-208.
- Stoneburner, D.L. 1978. Heavy metals in tissues of stranded short-finned pilot whales. *Sci. Total Environ.* 9:293-297.
- Sturkie, P.D. 1973. Effects of cadmium on electrocardiogram, blood pressure, and hematocrit of chickens. *Avian Dis.* 17:106-110.
- Sundelin, B. 1983. Effects of cadmium on Pontoporeia affinis (Crustacea: Amphipoda) in laboratory soft bottom microcosms. *Mar. Biol.* 74:203-212.
- Talbot, V.W., R.J. Magee, and M. Hussain. 1976. Cadmium in Port Phillip Bay mussels. *Mar. Pollut. Bull.* 7:84-86.
- Theede, H., N. Scholz, and H. Fisher. 1979. Temperature and salinity effects on the acute toxicity of cadmium to Laomedea loveni (Hydrozoa). *Mar. Ecol. Prog. Ser.* 1:13-19.
- Thorp, J.H., J.P. Giesy, and S.A. Wineriter. 1979. Effects of chronic cadmium exposure on crayfish survival, growth, and tolerance to elevated temperatures. *Arch. Environ. Contam. Toxicol.* 8:449-456.
- Jell, J.C., T.H. Christensen, and F. Bro-Rasmussen. 1983. Cadmium in soil and terrestrial biota with emphasis on the Danish situation. *Ecotoxicol. Environ. Safety* 7:122-140.
- Oppong, G. 1973. Heavy metals in shellfish from Scottish waters. *Aquaculture* 1:379-384.
- urner, J.C., S.R.B. Solly, J.C.M. Mol-Krijnen, and V. Shanks. 1978. Organochlorine, fluorine, and heavy metal levels in some birds from New Zealand estuaries. *N. Z. J. Sci.* 21:99-102.
- attuone, G.M., K.S. Griggs, D.R. McIntyre, J.L. Littlepage, and F.L. Harrison. 1976. Cadmium concentrations in rock scallops in comparison with some other species. *U.S. Energy Res. Dev. Admin.* UCRL 52022: 1-11.

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Vernberg, W.B., P.J. DeCoursey, and J. O'Hara. 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, Uca pugilator. Pages 381-425 in F.J. Vernberg, and W.B. Vernberg (eds.). *Pollution and physiology of marine organisms*. Academic Press, New York.

Voors, A.W., M.S. Shuman, and W.D. Johnson. 1982. Additive statistical effects of cadmium and lead on heart related disease in a North Carolina USA autopsy series. *Arch. Environ. Health* 37:98-102.

Watling, H.R., and R.J. Watling. 1976. Trace metals in oysters from Knysna Estuary. *Mar. Pollut. Bull.* 7:45-48.

Weis, J.S., and P. Weis. 1977. Effects of heavy metals on development of the killifish, Fundulus heteroclitus. *J. Fish Biol.* 11:49-54.

Westernhagen, H.V., V. Dethlefsen, and H. Rosenthal. 1980. Correlation between cadmium concentrations in the water and tissue residue levels in dab, Limanda limanda L., and plaice, Pleuronectes platessa L. *J. Mar. Biol. Assoc. U.K.* 60:45-58.

White, D.H., and M.T. Finley. 1978. Uptake and retention of dietary cadmium in mallard ducks. *Environ. Res.* 17:53-59.

White, D.H., R.C. Stendell, and B.M. Mulhern. 1979. Relations of wintering canvasbacks to environmental pollutants - Chesapeake Bay, Maryland. *Wilson Bull.* 91:279-287.

White, D.H., K.A. King, and R.M. Prouty. 1980. Significance of organochlorine and heavy metal residues in wintering shorebirds at Corpus Christi, Texas, 1976-77. *Pestic. Monit. J.* 14:58-63.

Williams, D.R., and J.P. Giesy, Jr. 1978. Relative importance of food and water sources to cadmium uptake by Gambusia affinis (Poeciliidae). *Environ. Res.* 16:326-332.

Windholz, M., S. Budavari, L.Y. Stroumtsos, and M.N. Fertig (eds.). 1976. *The Merck Index*, ninth edition. Merck and Co., Rahway, New Jersey.

Zarogian, G.E. 1979. Studies on the depuration of cadmium and copper by the American oyster Crassostrea virginica. *Bull. Environ. Contam. Toxicol.* 23:117-122.

Zarogian, G.E., and S. Cheer. 1976. Cadmium accumulation by the American oyster, Crassostrea virginica. *Nature* 261:408-410.